AMS-II experiment

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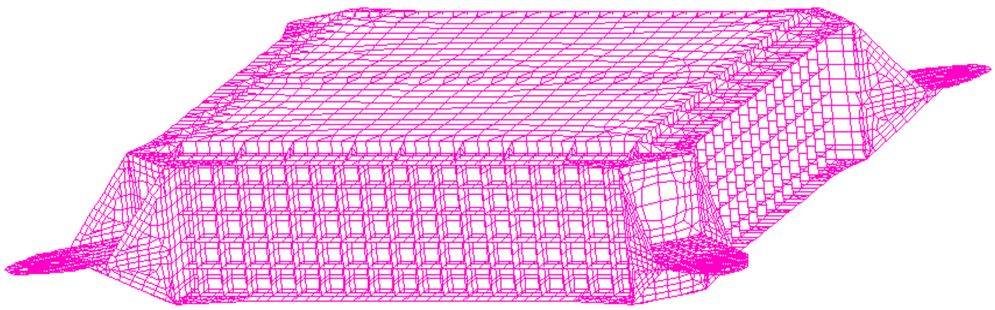
FEA on the ECAL flight model (optimization of the prototype)



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1 Introduction

1.1 Purpose of the document

The following study has a double goal :

- **Comparison** between the FEA from IHEP and LAPP (performed on the Ecal engineering model) :

  In order to compare two models of calculation with two different FE systems

  (SYSTUS and NASTRAN).
- Mass optimization on the current Ecal (engineering model) :

  To propose a redesign of some parts of Ecal (carvings on the strong structures).

Note that between the next Space Qualification Tests in Beijing and the "Mission success" in Italy, we will "adapt" our model to be closer to the SQT results. This will allows us to validate our propositions on mass optimization.

1.2 Loading conditions

In order to be « Space qualified » the calorimeter of AMSII experiment has to fulfill the following requirements (from LMCO) :

- Dynamic behavior: First natural frequency above **50 Hz**.
- "Static" behavior: Acceleration to be taken into account:

  With six degrees of freedom:

Nx = ± 7,8 g	**Rx = ± 145 rd/s^2**
Ny = ± 7,8 g	**Ry = ± 123 rd/s^2**
Nz = ± 11,1g	**Rz = ± 51 rd/s^2**

  With three degrees of freedom (equivalence given by LMCO):

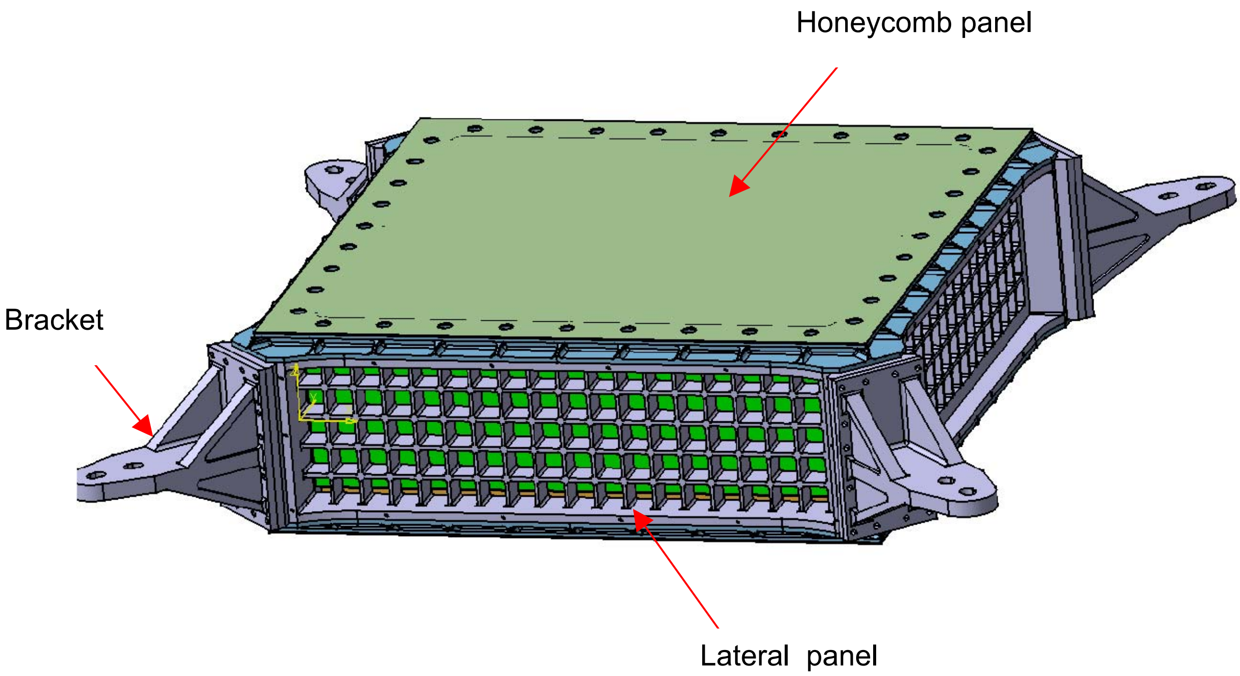
  Nx = ± 9,8 g
  Ny = ± 9,8 g
  Nz = ± 13,9 g

Note: All permutations and combinations of the 6 components has to be considered to get the worst case.

- Limit mass of the whole Ecal: 639 Kg allowed. Starting from the current Ecal mass estimate (5 Kg on the engineering model) this means that we have to gain **16 Kg** at least!

2 Description of the FE model

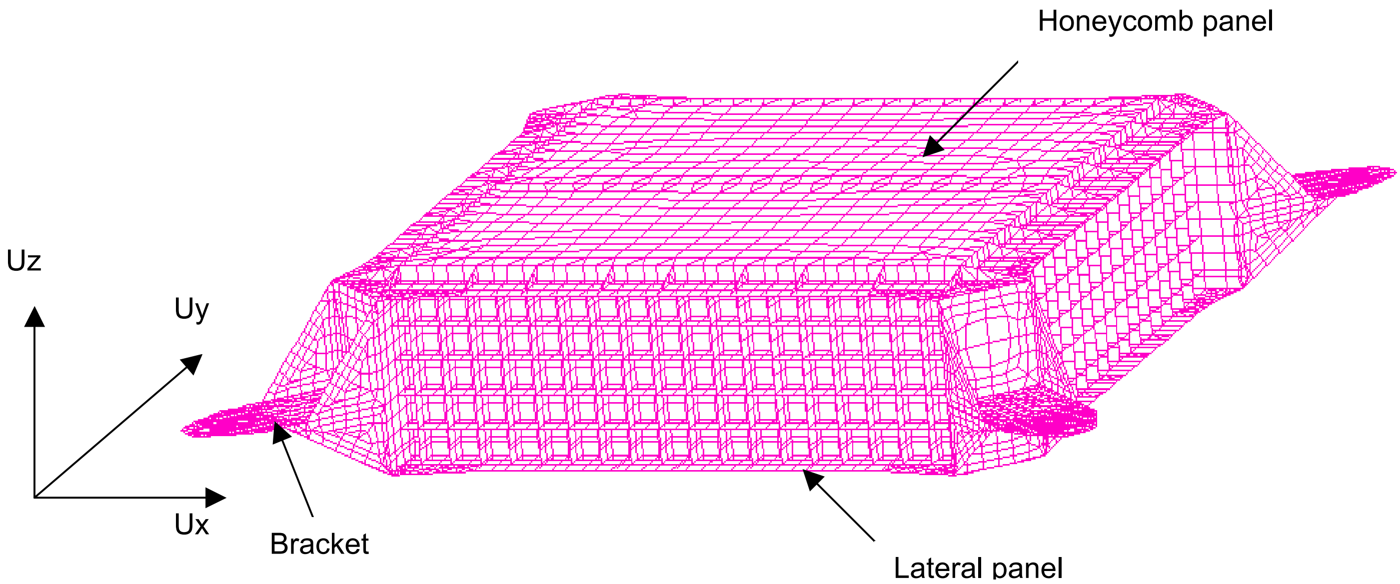
2.1 CAD design of ECAL



Note that we have two kinds of lateral panels: the ones with 5 ranks of PMT tubes and the ones with 4 ranks.

2.2 Overall meshing – Current ECAL

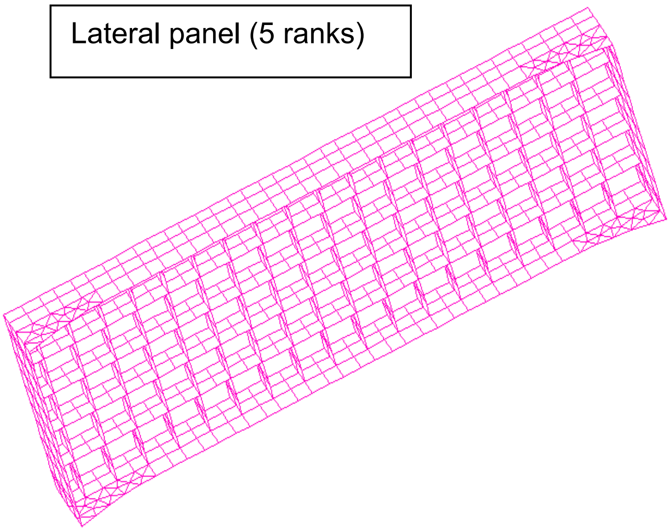
See below the Ecal meshing coming from SYSTUS software.



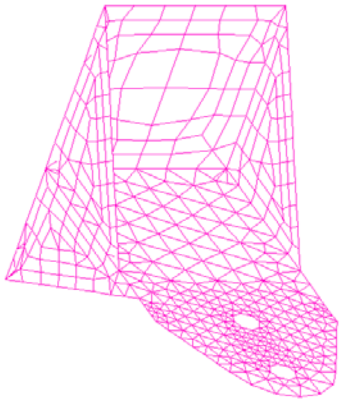
Meshing made of shell elements (structural parts) and solid elements (Pancake). A static-linear solver was used to performed calculations of deformations and stresses.

2.3 Meshing of Sub parts – Current ECAL

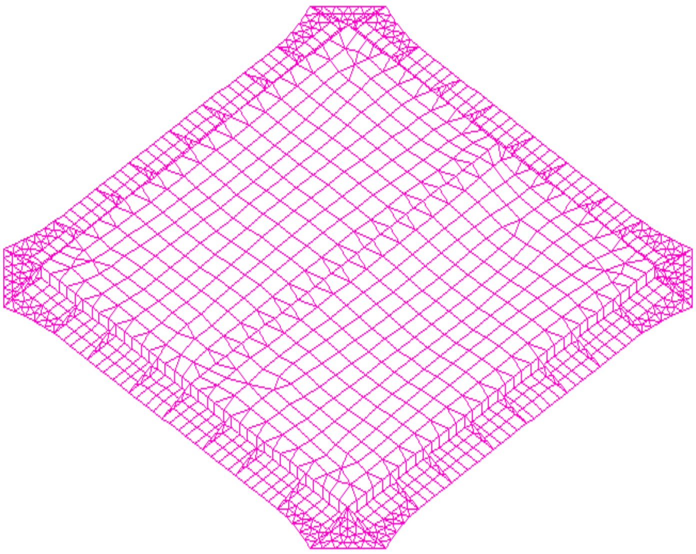
Lateral panel (5 ranks)



Bracket



Honeycomb frame + aluminum foil



Pancake + honeycomb core volumes

Honeycomb cores

Pancake

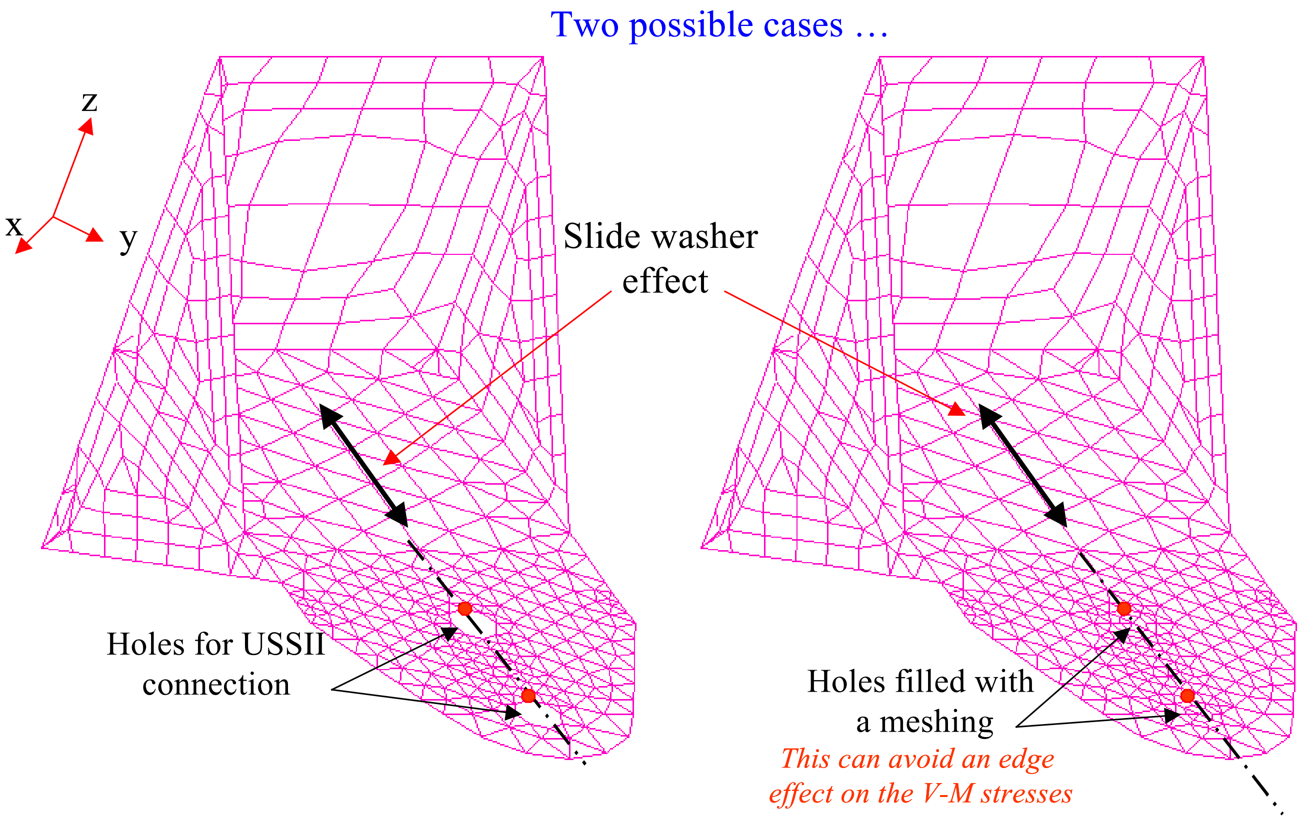
In conclusion, the model is made of **15000 nodes** and **21150 mesh elements**.

The difference of number between nodes and meshes is due to the fact that we have many superposed meshes in our model. For example, one aluminum foil (made of shell meshes) was put between the volumes from Pancake and honeycomb cores to simulate the behavior of the honeycomb panels.

Note that in this model the connection between honeycomb frame and bracket or lateral panel is fixed for all the nodes in contact. So, the loads on the screws cannot be controlled.

2.4 Boundary conditions

At the beginning different kinds of boundary conditions were used on bracket nodes: fixed, simply supported. In fact, these conditions have to simulate the behavior of the connection between USSII and ECAL brackets. After discussion with LMCO, it has been decided to consider a **slide movement** of brackets with respect to the USSII supports.



In conclusion, we used all the nodes on the hole edge. On each node, the movement in Z axis is fixed (**Uz=0**) when **Uy** and **Ux** are linked by the relation: **Uy+Uz=0**.

2.5 Material characteristics

The calorimeter is made of 3 different material :

- A Space Qualified Aluminum (7075 T 7351) for structural parts:

Young Modulus E = 72000 MPa
Density = 2800 Kg/m^3
Yield stress = 390 MPa
Ultimate stress = 470 MPa

- A composite material : honeycomb panels

The core :	Young Modulus = 698 MPa
	Density = 72 Kg/m^3
	Ultimate stress: about 3 MPa
The foils :	Young Modulus = 70000 MPa
	Density = 2800 Kg/m^3

- The "Pancake" considered as a composite material

(cf. Lapp note AMS-Me-Cal-001)

Young Modulus = 6300 MPa
Density = 6970 Kg/m^3
Yield stress = 4 MPa
Ultimate stress = 15 MPa

Concerning the "space qualified material" the 7000 series aluminum was chosen for his high yielding (and required by LMCO). This material will be put in the **flight Ecal model**. The Chinese material has different characteristic concerning the Yield and Ultimate stresses (see below the characteristics coming from the IHEP FEM note). This material will be put in our **engineering Ecal model** in order to compare the models.

Material Property of Aluminum from China:

Young modulus: E=69000 MPa,

yielding strength Fty=240Mpa,

ultimate strength Ftu=390Mpa.

Density=2700kg/m3.

2.6 Loading

Due to technical reasons (use of SYSTUS software) we can only consider the **"3 degrees of freedom" loading**. See paragraph 1.2 for details. In the future we will be able to simulate the 6 degrees of freedom loading (NASTRAN and SAMCEF software).

In order to "measure" the difference between 3 and 6 DoF, a calculation was performed on a simple model using Samcef software. The results on momentums and reaction forces at the boundary nodes (USSII interface) are shown on the next table.

Degree of freedom	Max. Reaction force	Max. Momentum
3 Dof	10,23 x 10^3 N	145 Nm
6 Dof	8,24 x 10^3 N	116 Nm

This means a difference of about 20% on such an equivalence. This could explain a difference with the Chinese calculations which were performed with 6 Dof.

3 Comparisons between IHEP and LAPP FEA

3.1 *Comparative table on Von-Mises stresses*

In order to get **650 Kg** in total (as required by our collaboration for the FEA), the density of structural part was adapted to take into account the "missing mass" (about 80 Kg coming from the light collection system). The other possibility was to adapt the pancake density, but we preferred to use the same procedure as IHEP.

Note that in this LAPP model, the boundary conditions used are the same as the IHEP ones (**Ux,Uy,Uz are fixed**). The sliding effect will be taken into account in the Flight Ecal model.

Below are shown the results on 4 different parts of Ecal (critical parts). The Margin of Safety (**MoS**) are calculated for IHEP and LAPP aluminums due to their similar Young modulus E (difference of 4%). The difference concerns only both Yield and Ultimate stresses.

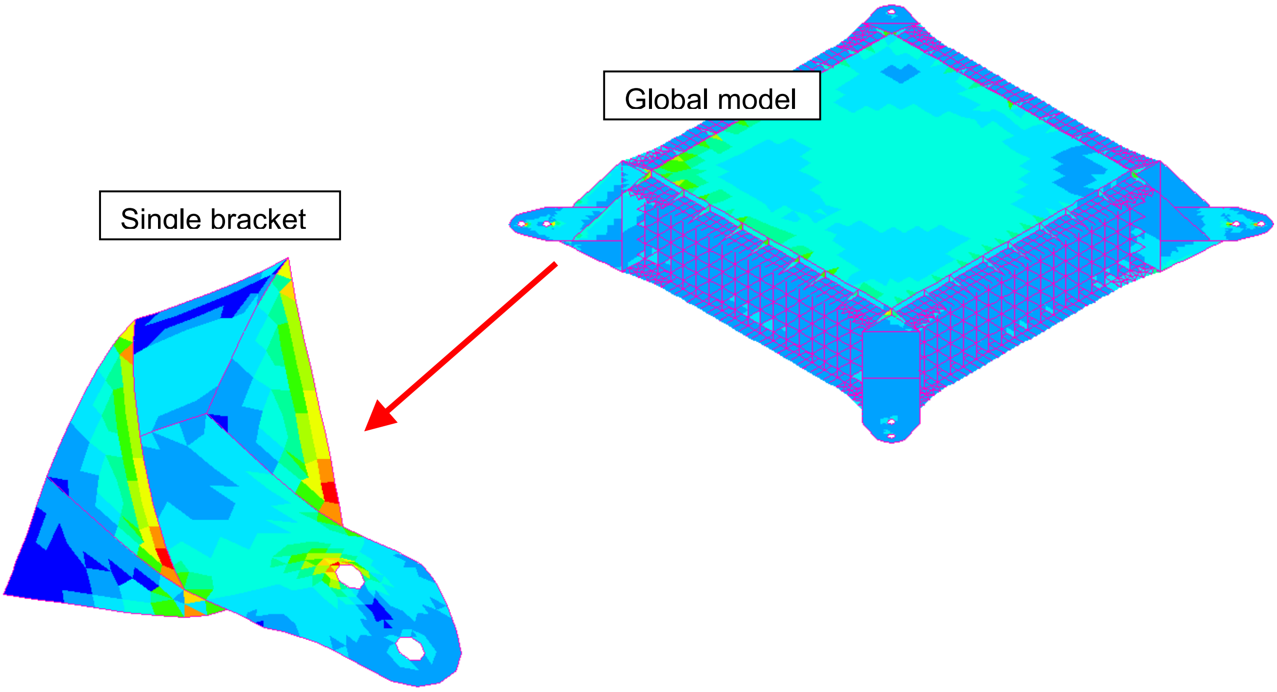
	Material		lateral panel	Bracket	Honeycomb foil	Honeycomb frame
IHEP model		**V-M stress**	**54.9 MPa**	**101 MPa**	**24.5 MPa**	**83 MPa**
		Coefficient of safety	1.2	1.2	1.2	1.2
	Mat IHEP	Yield stress	240 MPa	240 MPa	240 MPa	240 MPa
		MoS	2.64	0.98	7.16	1.38
	Mat LAPP	Yield stress	390 MPa	390 MPa	390 MPa	390 MPa
		MoS	4.9	2.2	12.3	2.9
LAPP model		**V-M stress**	**69.2 MPa**	**106.6 MPa**	**51**	**69.2 MPa**
		Coefficient of safety	1.2	1.2	1.2	1.2
	Mat IHEP	Yield stress	240 MPa	240 MPa	240 MPa	240 MPa
		MoS	1.89	0.88	2.92	1.89
	Mat LAPP	Yield stress	390 MPa	390 MPa	390 MPa	390 MPa
		MoS	3.7	2	5.37	3.7

Comments :

The maximum difference is within **20%**. Except the honeycomb foil which is far from our predictions. This is due to the fact that the Honeycomb model is quite different : LAPP model is made of a mixing of solid and shell elements instead of a shell model alone (IHEP) using a composite module of NASTRAN.

3.2 Von-Mises stresses mapping

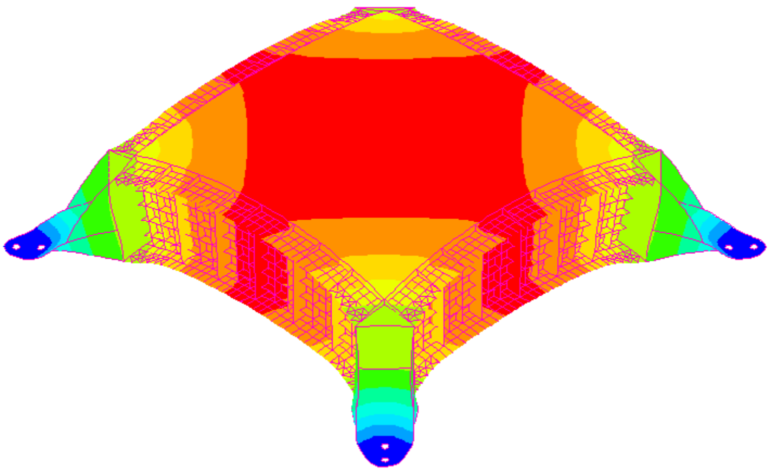
The maximum value of V-M stresses is located on the brackets (like in the IHEP FEA). See below the bracket mapping.



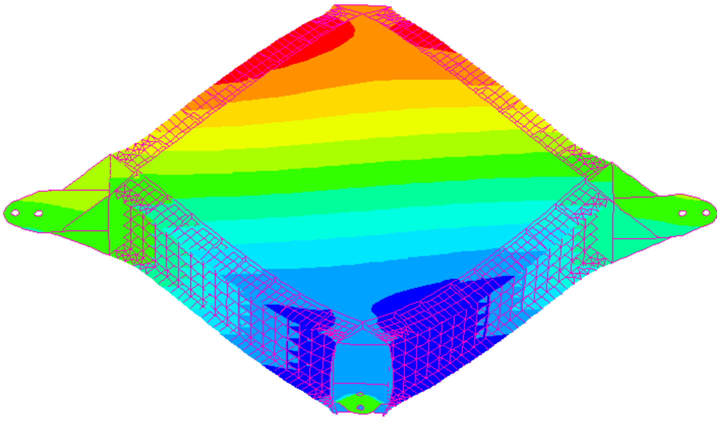
3.3 Comparative results on dynamic behavior

	1rst frequency	2^{nd} frequency
IHEP model	57.2 Hz	103.7 Hz
LAPP model	69.2 Hz	156.5 Hz

<u>Shape of the 1rst mode</u>:



Shape of the 2nd mode :



Comments:

Concerning the first two modes, the same shape are found: vertical deformation on the entire Ecal, and two opposite vertical deformations.

The difference on the first frequency is about **23%** (close to the difference on the V-M stresses).

3.4 Conclusions on the comparative study

The difference on the results is not only due to the loading (3 DoF instead of 6 DoF). Because this difference is also visible on the modal simulation which does not integrate any loading.

This may be explained by the type of shell elements ("thin shell" or "thick shell") used in the different models.

According to the results from the dynamic calculation, the LAPP model seems stiffer than the IHEP one.

Note that a new calculation is being proceeded at LAPP using "thick" shell elements on the structural parts to see their effect on the global stiffness.

4 Description of the model and possible modifications

4.1 Introduction

Different possibilities can be studied in order to save weight (16 Kg to be saved!)

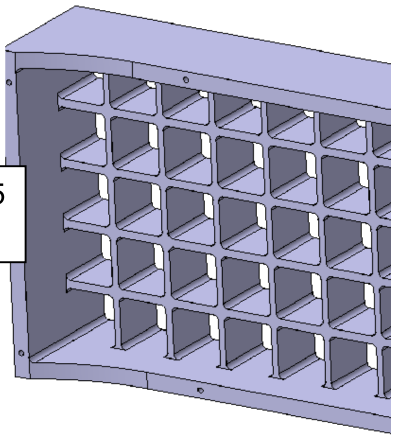
- **Honeycomb** panel height reduction (2 Kg saved on the two panels ...)
- The depth reduction of the square holes where PMT tubes fit on **Lateral panel**.
- Carvings and grooves on the thick parts of **Lateral panels**
- Thickness optimization on **brackets** (2-3 Kg in total, not more).

11 Kg in total

Some small changes are possible on the Pancake (which is the heavy part of Ecal) to save 4 Kg as a maximum (bottom lead foil changed into an aluminum one).

4.2 Lateral panels modification

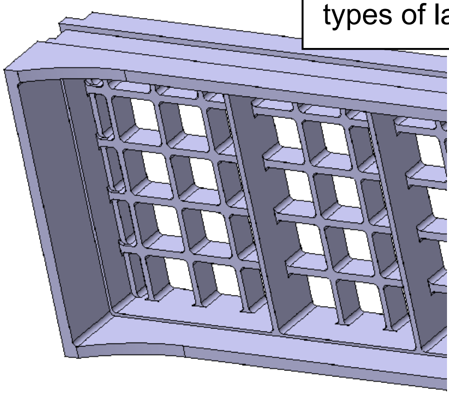
Original shape of the 5 ranks lateral panel



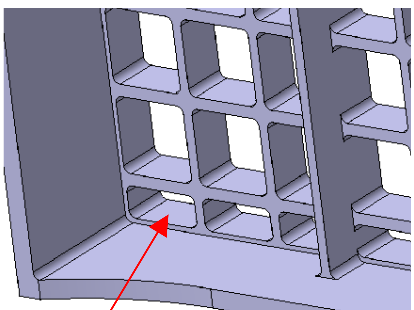
The original mass of the <u>5 ranks panels</u> is 6.2 Kg. By keeping the current design and making simple millings this allows to save 2.1 Kg / panel (4.2 Kg in total). The same procedure on the <u>4 ranks panels</u> saves 3.5 Kg / panel (7 Kg saved in total).

In conclusion, the mass saving on the four lateral panels is a little bit more than **11 Kg**.

Carvings and groove on the both types of lateral panel



Modifications on the 5 ranks lateral panel



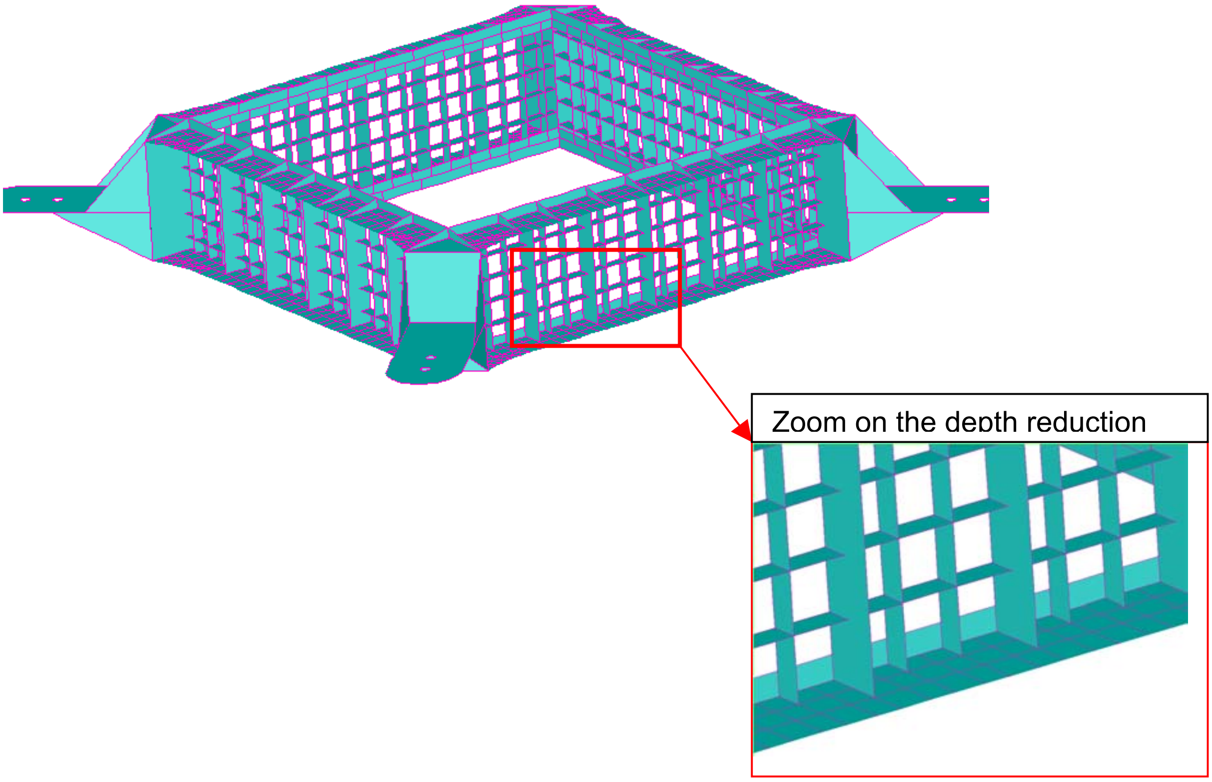
Milling of a “dead” part (no PMT tube fitting here)

Modifications on the 4 ranks lateral panel

5 New FEA model (also called « Flight model)

5.1 Geometry and meshing

In term of geometry the new version of Ecal (Flight model) follows the Engineering model except the geometry of the four lateral panels.

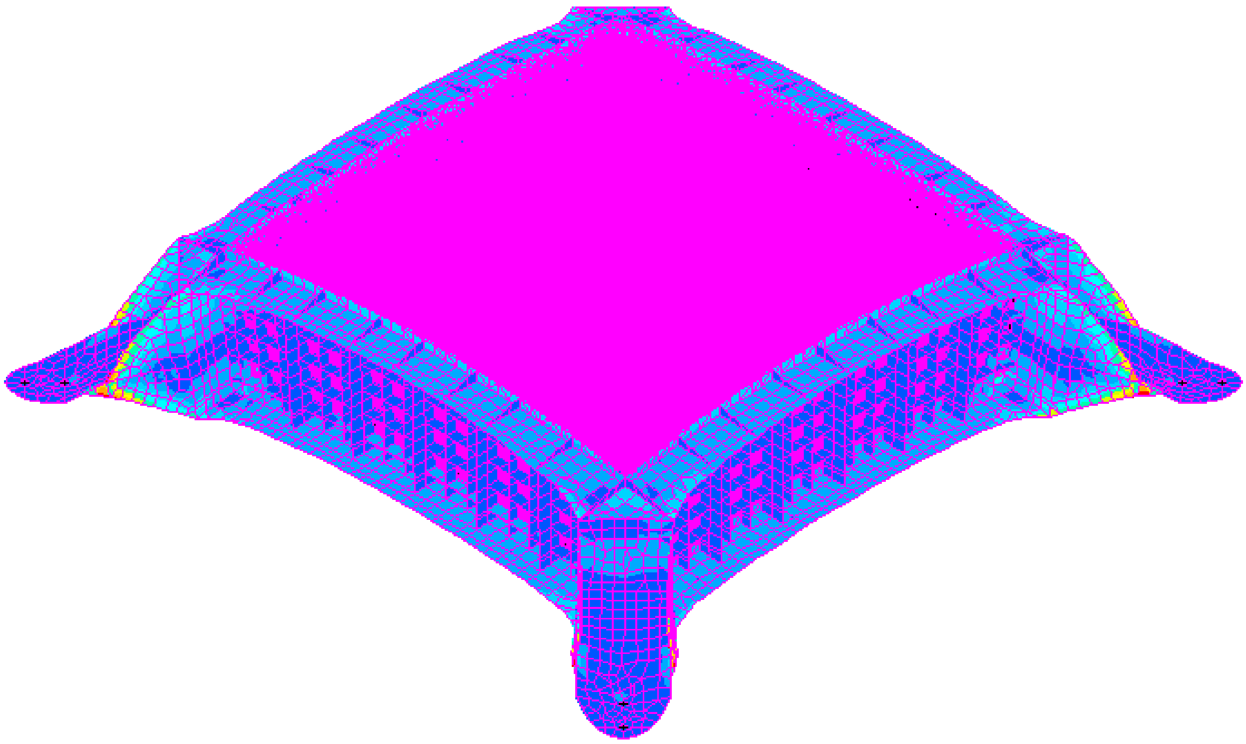


Note that the other parts are unchanged (concerning geometry) but the FE model allows to change the thickness on the shell elements. This means that a possibility is given to change easily the thickness on the brackets for example or on other strong parts.

The separated study on honeycomb panels showed no relevant mass saving on the whole structure (1-2 Kg?). That’s why no modification was put in the flight Ecal model. And the Honeycomb panels have a critical position (the limit is given when a non structural Pancake is taken into account in the FEA).

5.2 Discussions on results

See below the V-Mises stresses mapping.



Results given with different kind **of boundary conditions**:

- Calculation 1 : Ux, Uy and Uz are fixed on 2 nodes / bracket
- Calculation 2 : Ux, Uy and Uz are fixed on 16 nodes / bracket
  (all the nodes on the holes edge)
- Calculation 3 : Uz fixed and Ux+Uy=0 (sliding condition) on 16 nodes.

Material used :

See the 2.5 paragraph.

5.2.1 Results on dynamic behavior

	1rst frequency	**2^{nd} frequency**
Calculation 1	70.5 Hz	159.6 Hz
Calculation 2	70.7 Hz	161 Hz
Calculation 3	70.63 Hz	161.7 Hz

No relevant influence appeared according to three different boundary conditions. No change in term of modal shape.

5.2.2 Results on acceleration (3 DoF combination)

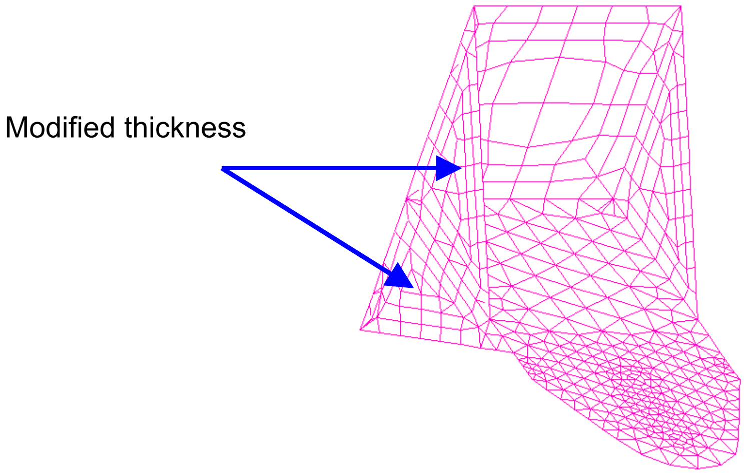
		lateral panel	Bracket	Honeycomb foil	Honeycomb frame
Calculation 1	**V-Mises stress**	69.3	237.3 *	51.7	69.3
	Factor of safety	1.2	1.2	1.2	1.2
	Yield stress	390 MPa	390 MPa	390 MPa	390 MPa
	MoS	**3.69**	**0.37**	**5.28**	**1.88**
Calculation 2	**V-Mises stress**	69	76.2	51.7	69
	Factor of safety	1.2	1.2	1.2	1.2
	Yield stress	390 MPa	390 MPa	390 MPa	390 MPa
	MoS	**3.7**	**3.27**	**5.29**	**3.7**
Calculation 3	**V-Mises stress**	69.5	76.1	51.8	69.5
	Factor of safety	1.2	1.2	1.2	1.2
	Yield stress	390 MPa	390 MPa	390 MPa	390 MPa
	MoS	**3.67**	**3.27**	**5.27**	**3.67**

* edge effect on the stress (hole edge on bracket): it's not a realistic stress value. This effect doesn't exist in the calculation 2 and 3.

No relevant effect on the resulting stresses according to the three different boundary conditions.

5.2.3 Results on acceleration with modified brackets

Discussion according to three different thickness on the vertical ribs (see below).



Boundary condition: sliding effect on 16 nodes / bracket.

Thickness		lateral panel	Bracket	Honeycomb foil	Honeycomb frame
10 mm	**V-Mises stress**	78.8 MPa	183.4 MPa	61.8 MPa	78.8 MPa
	Factor of safety	1.2	1.2	1.2	1.2
	Yield stress	390 MPa	390 MPa	390 MPa	390 MPa
	MoS	3.12	0.77	4.26	3.12
15 mm	**V-Mises stress**	72.9 MPa	107.5 MPa	61.4 MPa	72.9 MPa
	Factor of safety	1.2	1.2	1.2	1.2
	Yield stress	390 MPa	390 MPa	390 MPa	390 MPa
	MoS	3.46	2.02	4.29	3.46
20 mm	**V-Mises stress**	67.9 MPa	75.6 MPa	60.9 MPa	67.9 MPa
	Factor of safety	1.2	1.2	1.2	1.2
	Yield stress	390 MPa	390 MPa	390 MPa	390 MPa
	MoS	3.78	3.3	4.3	3.78

As foreseen the MoS is lowered when the rib thickness of bracket is reduced. But even with 10 mm thick the MoS (0.77) is > 0. Which is sufficient. A same study could be performed on the horizontal plate of bracket to save more mass.

5.2.4 Results on dynamic behavior

	1rst frequency	2^{nd} frequency
10 mm	55.4 Hz	126,2 Hz
15 mm	63.2 Hz	142.6 Hz
20 mm	70.6 Hz	161.7 Hz

Note the relevant influence of the ribs thickness in the first natural frequency. In this model the first frequency is still above 50 Hz (however Lapp FEA and IHEP FEA keep 20% difference, so we have to be prudent on the conclusions).

5.3 *Comparative study between Engineering and flight models*

This is only based on the LAPP FEA models performed on SYSTUS.

5.3.1 Results on acceleration (3 DoF combination)

This flight model only takes into account the modification on Lateral panel.

		lateral panel	Bracket	Honeycomb foil	Honeycomb frame
LAPP Engineering model	**V-Mises stress**	68.09 MPa	77.06 MPa	50.35 MPa	68.09 MPa
	Factor of safety	1.2	1.2	1.2	1.2
	Yield stress	390 MPa	390 MPa	390 MPa	390 MPa
	MoS	3.77	3.2	5.5	3.8
LAPP Flight model	**V-Mises stress**	69.55 MPa	76.13 MPa	51.77 MPa	69.55 MPa
	Factor of safety	1.2	1.2	1.2	1.2
	Yield stress	390 MPa	390 MPa	390 MPa	390 MPa
	MoS	3.67	3.27	5.27	3.67

This modification doesn't affect the MoS. Some part are reduced (on lateral panels) but in the same time the mass is lowered.

5.3.2 Results on dynamic behavior

	1rst frequency	2^{nd} frequency
LAPP Engineering model	71 Hz	161.9 Hz
LAPP Flight model	70.6 Hz	161.7 Hz

5.4 *Conclusions*

The lateral panel optimization seems not to affect to much the MoS on the whole Ecal. And this has the best contribution in mass saving (11 Kg). In addition, the first frequency is the same between engineering and flight models.

In the same time it seems easy to reduce the thickness of brackets (on horizontal and vertical plates) and the MoS are still acceptable. BUT the effect on the first frequency is relevant (too close to 50 Hz!) and the mass saving is small compared to the lateral panels.

In conclusion, we have to wait for the SQT results to get the real first frequency which is the main limit in our optimization work.